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Relation of strength and mineralogical attributes in Brazilian latosols

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ABSTRACT

There is a growing demand for the estimation of load support capacity of soils on a larger scale in mitigating compaction and other degradation forms of agricultural soils. In this study, we examined the relationship between load support capacity and soil mineralogy, using four latosol (oxisol) types. Our results showed that soil color could be used as a first discriminator of load support capacity in latosols. Hematitic (reddish) latosols were observed to have lower load support capacity when compared to the goethitic (yellowish) soils. We observed that the clay mineralogy is associated with soil structure development and consequently with the load support capacity of the soil. Our study has laid a foundation for large-scale estimation of strength attributes in latosols indicated by their structure, which is associated with their quite stable and simple mineralogy.

1. Introduction

Soils are complex assemblies of solids, liquids and gases with the solid component accounting for about 50% of the volume, while gases (air) and liquid, typically water, makes up the remaining 50%. The strength of soils (ability to withstand applied stress due to loading without the loss of its structure), to a considerable extent is influenced by the proportion and composition of the solid component. The soil solid component consists of about 45% minerals (inorganic component) and 5% organic matter (Sparks, 1995). The inorganic component is known to include both primary and secondary minerals ranging in size from clay (<0.002 mm) to sand (2–0.05 mm). Minerals are natural inorganic compounds with definite physical, chemical and crystalline properties influencing the physical and chemical properties of the different soil types.

Latosol (oxisols – *U.S. Soil Taxonomy*, ferralitiques – *France classification* and ferralsols – *World Reference Base for Soil Resources*) are the most common soil type in Brazil, representing more than 50% of the land mass (Curi, 1983; Camargo et al., 1987; Ker, 1997; Reatto et al., 2007). They are mainly made up of secondary minerals due to their long weathering history when the parent rock is not too sandy (Curi, 1983). The high degree of weathering–leaching to which latosols have been exposed to was reflected in the dominance of 1:1 clay minerals, Fe- and Al-oxides (in this paper, this general term includes oxides, hydroxides and oxyhydroxides), quartz and other highly resistant minerals in their mineralogy (Curi and Franzmeier, 1984). Latosols vary in color from reddish to yellowish depending on the parent rock, pedogenetic processes and climate (Curi, 1983; Marques et al., 2004). The structure of the latosols found in the Brazil is mainly associated with the clay fraction mineralogy (Embrapa, 2006; Ferreira et al., 1999a,b).

The study by Ferreira et al. (1999a) on seven latosols samples from Minas Gerais and Espírito Santo States of Brazil had shown that the physical properties associated with the soil structure were markedly influenced by the mineralogy of the clay fraction. Similarly, Ajayi et al. (submitted for publication) reported some relationships between soil inherent strength and the clay minerals assemblage in latosols samples collected in Rio Grande do Sul, Minas Gerais and Espírito Santo States of Brazil. Reatto et al. (2007) in an experiment using latosols from the Brazilian Central Plateau showed that, their saturated hydraulic conductivity varied mainly according to the clay content and the development of large pores, but had no close link with the mineralogy of the clay fraction. Similarly, Ferreira et al. (1999b) observed that permeability in seven types of latosols samples they studied, increases with the clay content.

Recent awareness on the extent of soil degradation resulting from the use of heavy machinery and equipment in agriculture and

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forestry operations, and its economic and environmental consequences (Flowers and Lal, 1998; Conlin and Driessche, 2000; Neve and Hofman, 2000; Hamza and Anderson, 2005), demands better understanding of the load bearing capacities of soils at larger, economic and more representative scale (Leij et al., 2002; Or and Ghezzehei, 2002; Kirby, 2007).

Load bearing capacities of soils could be described by the relationship of the soil's preconsolidation pressure and water suction. Preconsolidation pressure reveals the maximum pressure that should be applied to a soil in order to avoid soil compaction (Defossez and Richard, 2002; Dias Junior et al., 2005; Silva et al., 2006; Veiga et al., 2007; Rücknagel et al., 2007), It is a factor based on the soil. Water suction on the other hand could be controlled, thus, it is basically a management factor. In this study, our objective was to establish the relationship between soil strength and soil mineralogy using four latosol types, associated with varied parent materials and climate in Brazil. The approach would facilitate large-scale estimation of load bearing capacities of soils and also assist in formulating appropriate management decisions for sustainable agricultural land use.

2. Materials and methods

2.1. Site description and sampling protocol

Undisturbed soil samples were collected from four sampling pits at Santo Ângelo, Rio Grande do Sul State (RGS); Aracruz, Espírito Santo State (ESP); Uberlandia, Minas Gerais State (UBJ); and Lavras, Minas Gerais State (LAV). The selected sites represent geographically distinct sub-regions, wide ranges of ecological conditions and cultivation practices. They also present the ranges of latosols that had been associated with different type of parent materials in Brazil condition (Table 1).

Seven samples were collected in 6.5 cm × 2.5 cm aluminium rings in the B horizons at all the sites using Uhland sampler. The sampling device was pushed carefully into the soil using a falling weight. The sampling pits (1 m × 2 m × 1 m) were dug very carefully to guard against self-compaction of the soil layers. The samples were collected randomly in each pit to ensure good representation. The samples were collected between 80 and 100 cm depth at the sites. As these soils are very homogeneous in morphological terms, we choose to collect the samples in the "clean B horizon" in order to avoid as much as possible the organic matter influence on soil attributes. In this way, our data can be extrapolated to the B horizon top where possible damage due to traffic can occur. Also in some Brazilian regions, the soil is being prepared up to 90 cm depth aiming to favor a good root distribution of perennial plants, such as *eucalyptus* sp. At each point of sample collection, the ring filled with soil was removed from the Uhland sampler, and wrapped with plastic materials and paraffin wax until compressibility and other tests were performed.

2.2. Physical, chemical and mineralogical characterization

In the laboratory, the soil samples were carefully trimmed to the size of their respective rings, whose inner diameter, height and weight had been pre-measured. This was used to determine the initial field bulk density of each sample. The disturbed soil samples scraped near the intact soil cores were air-dried and passed through a 2 mm sieve and stored in plastic bags prior to other analyses.

Basic soil characterization of the samples was performed according to Brazilian standard procedures as described in Embrapa (1997). Particle-size-distribution was determined using the pipette method after dispersing with 1N NaOH. Particle density was determined using 95% hydrated alcohol with 20 g of air-dried soil material in a 50 ml pycnometer.

For the mineralogical characterization, we determined Si, Al, Fe, Ti and P after digestion with 9.4 M H_2SO_4. This method is a standard procedure in Brazilian soil survey and is assumed to reflect the composition of the clay fraction. Gibbsite (Gb) and kaolinite (Ka) contents were determined in the iron-free clay fraction, while, goethite (Gt) and hematite (Hm) contents were determined in the iron-concentrated clay fraction according to Kampf and Schwertmann (1982). The hematite proportion (h_p) of the sample was calculated as $h_p = Hm/(Hm + Gt)$ and gibbsite proportion (g_p) as $g_p = Gp/(Gb + Ka)$, based upon the mineral peak area in the X-ray diffractograms.

X-ray diffractograms were obtained using a Philips diffractometer, with Co Kα radiation and Fe filter. The non-oriented slides were scanned from 4° to 50° 2θ (free-iron clay) and 25° to 48° 2θ (iron-concentrated clay), using 0.02° 2θ steps and 1 s counting times per step.

Soil colors were determined through visual comparison with the Munsell soil color charts in moist samples (Munsell soil color charts, 1992).

2.3. Compressibility test

Seven samples each, of the prepared soil cores were saturated by capillary with distilled water and equilibrated to 2, 6, 10, 33, 100, 500 and 1500 kPa, on ceramic plates inside a pressure chamber or on pressure table. The undisturbed soil samples at the different water suctions were then subjected to uniaxial compression test using a pneumatic S-450 Terraload floating ring consolidometer (Durham Geo Enterprises, USA). For the test, the undisturbed soil samples were kept within the coring cylinders, which were placed into the compression cell, and afterward submitted to pressures of 25, 50, 100, 200, 400, 800 and 1600 kPa. Each pressure was applied until 90% of the maximum deformation was reached (Taylor, 1948) and then the pressure was increased to the next level. The 90% of maximum deformation was determined by drawing a straight line through the data points of the initial part of the curve obtained when dial readings were plotted versus square root of the time, until this line intercepts the *y*-axis (dial

Table 1
Sampling site and soil descriptions

Label	Geographical coordinate and altitude	Climatic description	Brazilian soil classification	Parent material	Native vegetation
LAV	21°13′47″S; 44°58′6″W, 918 m	Gentle temperate with dry winter and rainy summer	Dystroferric red latosol	Gabbro	Forest
UBJ	18°58′37″S; 48°12′05″W, 866 m	Tropical monsoonal with dry winter and rainy summer	Acric red latosol	Tertiary detritic cover sediments	Cerrado
ESP	19°47′10″S; 40°16′29″W, 81 m	Moisty tropical with dry winter and rainy summer	Dystrocohesive yellow latosol	Barreiras group sediments	Forest
RGS	28°16′16″S; 54°13′11″W, 290 m	Moisty tropical without long dry period	Dystroferric red latosol	Basalt	Forest

Table 2
Physical and morphological characteristics of the latosols samples studied

Soil	Munsell color	Sand ($g\ kg^{-1}$)	Silt ($g\ kg^{-1}$)	Clay ($g\ kg^{-1}$)	Pd ($kg\ m^{-3}$)	Bd ($kg\ m^{-3}$)
LAV	10R 4/8	160	190	650	2.80	1.06
UBJ	2.5YR 4/8	300	80	620	2.67	0.96
ESP	10YR 6/6	490	60	450	2.70	1.73
RGS	10R 5/6	90	170	740	2.80	1.30

Pd, particle density; Bd, bulk density.

readings). A second straight line was drawn from this intersection with all abscissas 1.15 times as large as corresponding values on the first line. The intersection of this second line and the laboratory curve is the point corresponding to 90% consolidation (Taylor, 1948).

2.4. Analyses

The applied pressure versus deformation data were used to construct the soil compression curves, from which the preconsolidation pressures (σ_p) were determined following the procedure of Dias Junior and Pierce (1995). The preconsolidation pressures values were thereafter plotted against the soil water potential and a regression line fitted from a function in the form $\sigma_p = a + b \ln \Psi_m$ (Oliveira et al., 2003). The regression line is the bearing capacity model of the soils under study. It represents the adjustment of preconsolidation pressures to varying water matric potential. The regression analyses were accomplished using the software Sigma Plot 10.0 (Jandel Scientific).

3. Results and discussion

3.1. Soil color

The colors of the different soil samples determined using the Munsell soil color charts are presented in Table 2. Soil colors are indices of the soil forming process and had been used extensively in the classification of Brazilian soils (Curi and Franzmeier, 1984; Fontes and Weeds, 1991; Fontes and Carvallho, 2005; Embrapa, 2006) (Table 2).

The red color of samples RGS, LAV, and UBJ indicates the prevalence of hematite (α-Fe_2O_3) in the samples. The Munsell color of the sample of ESP suggests the dominance of goethite (α-FeOOH) in the sample. The hematite (Hm)/(Hm + Gt (goethite)) ratios in Table 3 are consistent with these indications. We could therefore classify the different latosols studied into two main groups as: hematitic or red soil comprising of samples from Santo Angelo (RGS), Lavras (LAV) and Uberlandia (UBJ), and goethitic or yellow soils made up of sample from Aracruz (ESP).

3.2. Comparison of bearing capacity models

The bearing capacity models of the different samples are presented in Fig. 1 with its coefficient of determination and the level of significance.

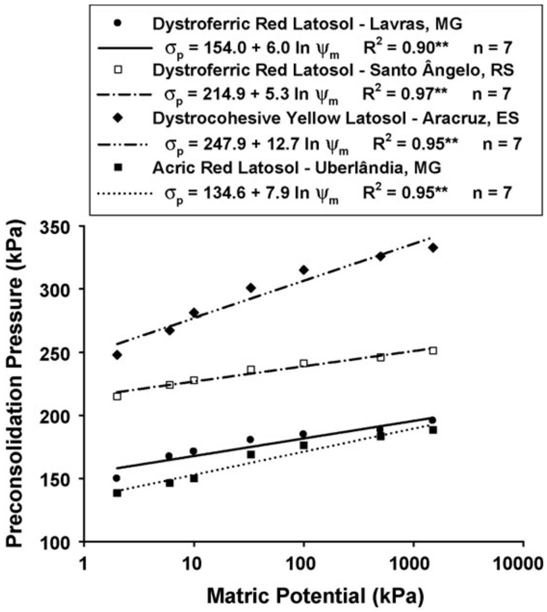

Fig. 1. Bearing capacity models for latosol samples collected at all sites.

The comparison of the bearing capacity models showed that soil strength in all the samples varied with the water potential status. The observation was consistent with results from several studies on the strength of soils (Ohu et al., 1986; Mosaddeghi et al., 2003; Peng et al., 2004; Pereira et al., 2007; Dias Junior et al., 2007). At high water potential, the strength of soils improves with slight changes in water potential. This however depends on the structure of the soil and the composition of the soil's solid component (Imhoff et al., 2004; Reatto et al., 2007). At low water potential, soil strength is considerably reduced, due to a high pore water pressure created within the soil. The strength of the soil samples studied increased in the order: acric red latosol (UBJ) < dystroferric red latosol (LAV) < dystroferric red latosol (RGS) < dystrocohesive yellow latosol (ESP).

Our results showed the hematitic soils/reddish soils (RGS, LAV and UBJ) had lower load support capacity than the goethitic soils/yellowish soil (ESP). This observation showed that soil color could be used as a first tool to delineate soil strength attributes.

3.3. Soil strength and mineralogy

Clay minerals are assemblages of tetrahedral and octahedral sheets arranged in unique format depending among other things on the oxides levels, parent materials and soil age (Sparks, 1995). The arrangement of these minerals affect the structure of the soil, and consequently the strength attributes of the soil samples (Spoor et al., 2003; West et al., 2004).

In the dystrocohesive yellow latosol (ESP) the absence of gibbsite and the very low amount of iron oxides (Table 3), favors the face-to-face arrangement of kaolinite plates, contributing for the highest bulk density value (Table 2) and the highest load

Table 3
Oxides content and other mineralogical content of the latosol samples studied

	SiO_2 ($g\ kg^{-1}$)	Al_2O_3 ($g\ kg^{-1}$)	Fe_2O_3 ($g\ kg^{-1}$)	P_2O_5 ($g\ kg^{-1}$)	TiO_2 ($g\ kg^{-1}$)	Hm/(Hm + Gt)	Gb/(Gb + Ka)
LAV	158	279	220	0.49	27	0.73	0.45
UBJ	129	268	106	0.34	20	0.83	0.54
ESP	176	172	11	0.07	12	0.00	0
RGS	269	237	227	0.21	3.84	1.00	0

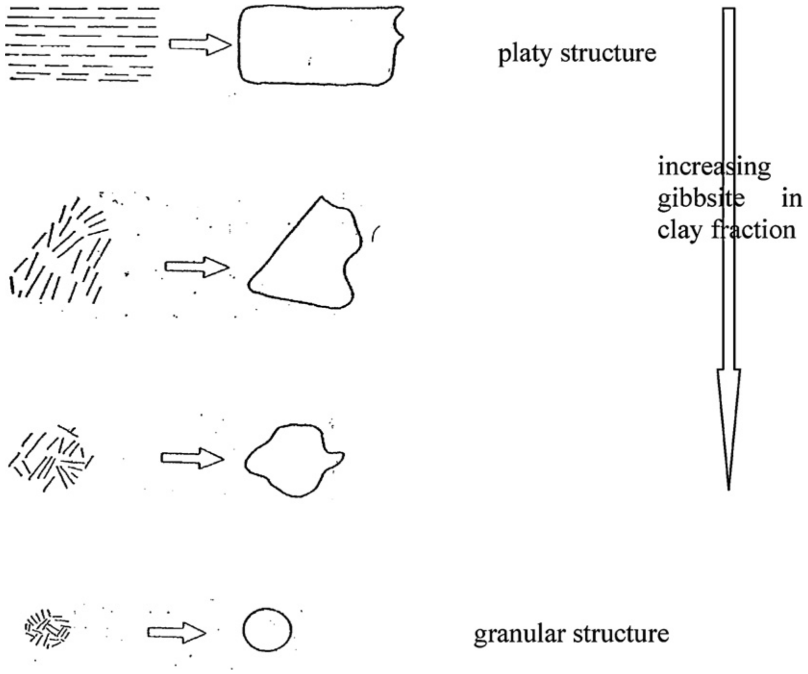

Fig. 2. Dynamics of soil structure as a function of increasing aluminum oxide levels (UFV, 1979).

support capacity of this soil (Fig. 1). The cohesive aspect of this soil, easily identifiable in the field when the soil is somewhat dry, is a distinctive character of this soil class, similar to hard-setting soils (Giarola et al., 2003).

In the dystroferric red latosol collected at Santo Angelo (RGS), the clay mineral assemblage was dominated by kaolin compounds; rich in iron oxides but with no gibbsite. This situation is associated with blocky structure, contributing for elevating the bulk density and lowering the porosity of the soil (Ferreira et al., 1999b; Resende et al., 2005). This condition helps to explain the high load support capacity of this soil even at lower water suction.

Contrarily in the dystriferric red latosol collected at Lavras (LAV) and in the acric red latosol collected at Uberlândia (UBJ), the rich presence of gibbsite in the clay fraction hinders the face-to-face arrangement of the kaolinite sheets. The gibbsite acted rather as a wedge between the kaolinite sheets, thereby favoring a granular structure in the soil (Fig. 2) (UFV, 1979). This structure contributes for low bulk density, and is particularly susceptible to compaction at high water suction. Consequently the soil has lower load support capacity compared to the blocky structure associated with the face-to-face arrangement (RGS).

4. Conclusions

Our results showed that soil colors could be used as a first discriminator of load bearing capacity in latosols. Hematitic latosols (red soils) were observed to have lower load support capacity when compared to the goethitic soil (yellow soil). Among the red soils, there are behavior differences associated with their mineralogy. As the gibbsite content increases, the load support capacity of the soil decreases. We observed that clay mineralogy is associated with soil structure and consequently the load support capacity of the latosols.

Our results help to understand how load support capacity and susceptibility to compaction is influenced by soil structure which is associated with soil mineralogy in these very weathered soils of Brazil.

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